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SHOULDER

Partial supraspinatus tears are associated with tendon lengthening

Nadja A. Farshad-Amacker · Florian M. Buck · Mazda Farshad · Christian W. A. Pfirrmann · Christian Gerber

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Abstract

Purpose Tendon tear may result in muscular retraction with the loss of contractile amplitude and strength of the rotator cuff muscles. Currently, neither a validated method of measuring supraspinatus tendon length nor normal values are known. It was therefore the purpose of this study to measure the normal length of the supraspinatus tendon and to determine whether partial tears are associated with changes in tendon length.

Methods MR examinations of 49 asymptomatic volunteers and 37 patients with arthroscopically proven, isolated partial tears of the supraspinatus tendon were compared. The ratio of the extramuscular tendon length to the distance between the footprint and the glenoid surface was calculated (TL/FG ratio). Tendon length measurements were taken by two independent readers at the bursal and articular surfaces at the anterior, the central and the posterior parts of the tendon.

Results TL/FG ratios at the bursal surface of tendons with partial tears were significantly higher than those in the control group [anterior: 0.78 ± 0.20 vs. 0.66 ± 0.15 ($p < 0.05$); central: 0.61 ± 0.13 vs. 0.52 ± 0.10 ($p < 0.05$); posterior: 0.57 ± 0.15 vs. 0.52 ± 0.10 ($p < 0.05$)]. At the articular surface, differences were significant only anteriorly [0.60 ± 0.13, vs. 0.54 ± 0.10 ($p < 0.05$)]. A cut-off TL/FG ratio of 0.63 for measurements at the bursal surface in the center of the tendon achieved a sensitivity of 46 % and a specificity of 92 % for the identification of partial cuff tearing.

Conclusion A reproducible method for measurement of extramuscular supraspinatus tendon length is described. Partial tearing of the supraspinatus tendon is associated with significant tendon lengthening, suggesting failure in continuity, and this is most reliably measured on the bursal surface.

Level of evidence III.

Keywords Supraspinatus · Tendon · Partial tears · Tendon length · Rotator cuff tear

N. A. Farshad-Amacker (✉) · F. M. Buck · C. W. A. Pfirrmann
Division of Radiology, Balgrist University Hospital, University of Zurich, Forchstrasse 340, 8008 Zurich, Switzerland
e-mail: nadja.amacker@usz.ch

M. Farshad · C. Gerber
Department of Orthopaedics, Balgrist University Hospital, University of Zurich, Forchstrasse 340, 8008 Zurich, Switzerland

Introduction

In adults, partial tears of the supraspinatus tendon have a prevalence of 13–37 % [6, 29] and may be associated with shoulder pain [21]. Biomechanically, partial tears generate increased stress to the remaining, intact cuff tendon fibres and may progress to full-thickness tears [24, 34]. Dynamic in vivo ultrasonography has revealed that partially torn supraspinatus tendons functionally behave like fully torn tendons: whereas normal tendons increase in thickness upon musculotendinous contraction, partially torn tendons do not, but rather lengthen [9]. Whether, however, a partially torn tendon has failed in continuity and is therefore also lengthened at rest is unknown. If so, the amount of retraction in continuity as a result of the partially torn and lengthened tendon with corresponding muscle retraction might guide the treatment approach.

MRI is the most sensitive, non-surgical examination to assess partial tendon tearing. It has been found to have a remarkably variable sensitivity, reaching from 38 to 93 % [15, 25, 26, 30, 31], but a good specificity (70–97 %)

[15, 25, 26, 30, 31]. A reliable criterion for partial tears is a substance defect in the tendon. Intratendinous lesions are particularly difficult to diagnose by MRI, ultrasonography and arthroscopy [7, 13, 18, 21, 28] but account for up to 8–20 % of the partial tears [6, 12, 32, 33]. The only established MR criterion for an intratendinous tear is a T2w hyperintense signal representing fluid within the tendon [20]. With tendon tear healing, the defect is replaced by granulation or scar tissue that might be difficult to differentiate from tendon degeneration or tendinopathy by means of MRI [1, 10, 19]. If intratendinous tearing was associated with failure in continuity and thereby lengthening of the tendon, such lengthening could become a key finding for partial tears and particularly for intratendinous tears. A reproducible method to measure the length of the supraspinatus tendon and therefore normal values for tendon length, however, is not yet available.

The hypothesis of this investigation is that if a rotator cuff tendon is partially torn, it has failed in continuity and is elongated so that the distance between the footprint and the musculotendinous junction is increased. If true, this might have direct clinical consequences since an increased length of the supraspinatus tendon may result in reduced resting length of the muscle, representing a functional rather than a structural tear. Furthermore, it might explain that some partial tears are associated with fatty infiltration [22] of the supraspinatus muscle, a phenomenon that has been documented to be irreversible and related to muscular retraction [8, 16, 17].

It was therefore the purpose of this study to define the normal length of the supraspinatus tendon and to test the hypothesis that partial tearing of the supraspinatus tendon is associated with elongation of this tendon.

Materials and methods

A retrospective case–control study was performed with 49 asymptomatic volunteers as the control group (21 males and 28 females) with a mean age of 35 ± 9 years (ranging from 22 to 59 years) who underwent MR imaging of their shoulder for another investigation and 37 patients (26 males and 11 females) with arthroscopically proven, isolated partial tears ($n = 32$ articular and $n = 5$ bursal) of the supraspinatus tendon with a mean age of 47 ± 8 years (ranging from 26 to 60 years) as the case group.

For the control group, the institutional review board had approved the study and informed consent was obtained from all volunteers. Exclusion criteria for the asymptomatic volunteers were prior trauma or surgery, shoulder pain or functional impairment.

For the case group, all consecutive patients between 2002 and 2010 with symptomatic shoulders who had a preoperative MRI and an arthroscopically proven partial tear were retrospectively included in the study. The exclusion criteria for the case group were prior shoulder surgery, surgery >7 months after the MR diagnosis, associated other rotator cuff tears, full-thickness supraspinatus tear, shoulder instability or shoulder dislocations and age of more than 60 years.

Imaging protocol

The control group underwent MR imaging in a standardized supine position with the arm in a neutral position without intra-articular contrast medium injection. MR imaging was performed with a 1.5-T system (Avanto or Espree; Siemens Medical Solutions, Erlangen, Germany) or a 3T system (Verio, Siemens Medical Solutions, Erlangen, Germany), depending on the availability of the systems. Sequences included an oblique coronal, fat-saturated (FS) intermediate-weighted (PDw) turbo spin-echo (TSE) sequence (repetition time (TR)/echo time (TE) 3,000 ms/13 ms; section thickness 4 mm; intersection gap 4.8 mm; flip angle 150°; field of view (FOV) 16 cm; matrix 512 × 512 pixels; number of excitations (NEX) 1; echo train length (ETL) 7); an oblique sagittal T1-weighted (T1w) spin-echo (SE) sequence (TR/TE 525 ms/12 ms; section thickness 4 mm; intersection gap 5.2 mm; FOV 16 cm; matrix 512 × 512 pixels; NEX 1); an oblique coronal T2-weighted (T2w) fat-saturated (FS) TSE sequence (TR/TE 3,130 ms/72 ms; FOV 16 cm; matrix 512 × 512 pixels; NEX 1; section thickness 4 mm; intersection gap, 4.8 mm; flip angle, 150°; ETL 11); and, without fat saturation in the axial plane, an oblique sagittal STIR sequence (TR/TE 5,500 ms/18 ms; inversion time 150 ms; section thickness 4 mm; FOV 16 cm; matrix 512 × 512 pixels; NEX 1; ETL 7).

The case group received MR arthrography with an intra-articular contrast medium injection prior to MR imaging in a standardized fashion. Under fluoroscopic control 1 ml of local anaesthetic (mepivacaine hydrochloride 2 %; Scandicain; AstraZeneca, London, England), 1 ml of iodinated contrast agent (iopamidol, 200 mg/ml; Iopamiro 200; Bracco, Milan, Italy) and 10 ml of diluted MR contrast agent (2 mmol/l of gadopentetate dimeglumine, Magnevist; Bayer Schering Pharma, Berlin, Germany) was injected. The application of intra-articular contrast medium is a standardized technique at our institution for shoulder imaging to increase the accuracy of detection of shoulder pathologies [3]. Between injection and MR imaging, there was a delay of less than 15 min. MR imaging was performed for the case group with a 1.5-T system (Symphony/Espree/Avanto; Siemens Medical Solutions, Erlangen, Germany). Sequences included an oblique coronal PDw FS TSE sequence (TR/TE 2,350 ms/12 ms; section thickness

4 mm; intersection gap 4.8 mm; flip angle 150°; FOV 16 cm; matrix 512 × 512 pixels; NEX 1; ETL 7); an oblique sagittal T1w SE sequence (TR/TE 500 ms/12 ms; section thickness 4 mm; intersection gap 5.2 mm; FOV 16 cm; matrix 512 × 512 pixels; NEX 1; ETL 1); an oblique coronal T2w FS TSE sequence (TR/TE 3,000 ms/91 ms; section thickness 4 mm; intersection gap 4.8 mm; FOV 16 cm; matrix 512 × 512 pixels; NEX 1; ETL 7); an oblique coronal T1w FS TSE sequence (TR/TE 792 ms/12 ms; section thickness 3 mm; intersection gap 3.6 mm; FOV 16 cm; matrix 512 × 512 pixels; NEX 1; ETL 1); without fat saturation in the axial plane (TR/TE 500 ms/12 ms, section thickness 3 mm; intersection gap 4.2 mm; FOV 16 cm; matrix, 512 × 512 pixels; NEX 1; ETL 1).

Since MR imaging has been performed over several years, the protocols may have small intersample differences without, however, affecting the overall image quality for diagnostic means.

Measurement of supraspinatus tendon length

Measurements were taken in a standardized fashion using the software OsiriX (version 4.1.1). The extramuscular part of the supraspinatus tendon was measured on the oblique coronal PDw sequence from the attachment site at the footprint to the musculotendinous junction, in millimetre. Measurements were taken at the bursal and articular surfaces at the anterior, central and posterior sections of the tendon using curved lines (Fig. 1a, b). The T1w oblique sagittal sequence at the level of the AC joint was used to define the appropriate oblique coronal sections for the anterior, central and posterior parts of the tendon (Fig. 1c, d). To normalize for the size of the glenohumeral joint, a ratio of the measured lengths of the tendon to the distance between the lateral edge of the footprint at the greater tuberosity and the glenoid plane was calculated (TL/FG ratio).

Interobserver agreement

To assess the interobserver agreement, a second, independent reader repeated the measurements made by first reader in the central part of the supraspinatus tendon.

Statistical analysis

For statistical analysis, the software Prism (version 4, GraphPad Software, La Jolla (CA), USA) was used. Means and standard deviations were used to report values. Box plots are depicted with whiskers from minimum to maximum. A two-tailed Student's *t* test was used for comparison between the groups once normal distribution was confirmed by the Kolmogorov–Smirnov test. A $p < 0.05$ was defined as significant. Receiver operating characteristics (ROC) and sensitivity, specificity, positive and negative predictive values as well as the odds ratio at a cut-off of the TL/FG ratio of 0.63 were calculated. Bland–Altman plots were used to evaluate the interobserver agreement.

Results

Extramuscular length of the supraspinatus tendon

At the bursal surface of the supraspinatus tendon, there was a significant difference in the TL/FG ratios between the control group and the patients with partial tears at the anterior (mean ± SD = 0.66 ± 0.15 and 0.78 ± 0.20; $p < 0.05$), central (0.52 ± 0.10 and 0.61 ± 0.13; $p < 0.05$) and posterior (0.52 ± 0.10 and 0.57 ± 0.15; $p < 0.05$) parts of the supraspinatus tendon (Fig. 2).

At the articular surface of the supraspinatus tendon, there was a significant difference only at the anterior part of the tendon (anterior: 0.54 ± 0.10 and 0.60 ± 0.13, $p < 0.05$; central: 0.51 ± 0.07 and 0.51 ± 0.11, $p = 0.9$; posterior: 0.44 ± 0.10 and 0.44 ± 0.11, $p = 1$) (Fig. 2).

Thirty-two of the partial tears were articular-sided and five were bursal-sided, with no significant difference in the TL/FG ratios (0.60 ± 0.14 and 0.68 ± 0.10, $p = 0.66$) between these two groups. Sixteen of the partial tears affected <50 % of the tendon thickness and fourteen affected >50 % of the tendon thickness, with no significant difference in the TL/FG ratios (0.59 ± 0.17 and 0.63 ± 0.09; $p = 0.33$). In seven patients, no exact description of the depth of the tear was available in the surgical notes.

The ROC analysis showed an area under the curve of 0.71 ($p < 0.05$, 95 % confidence interval 0.6–0.83). At a cut-off of the TL/FG ratio of 0.63, sensitivity, specificity, positive predictive and negative predictive values of 46, 92, 81 and 69 %, respectively, were observed for partial tears of the supraspinatus tendon measured at the bursal surface at the central aspect of the tendon (Table 1). The odds of being in the partial tear group when the ratio is greater than or equal to 0.63 are 9.56 (Table 1).

Interobserver assessment

The mean difference between the observers was 0.06 or less. The agreements on measurement of the two readers were better at the bursal surface of the supraspinatus tendon than at the articular surface; 95 % limit of agreement at the bursal surface ranges from −0.16 to 0.20 (control group) and −0.13 to 0.24 (partial tears), and at the articular surface, it ranges from −0.14 to 0.19 and −0.22 to 0.30, respectively (Fig. 3).

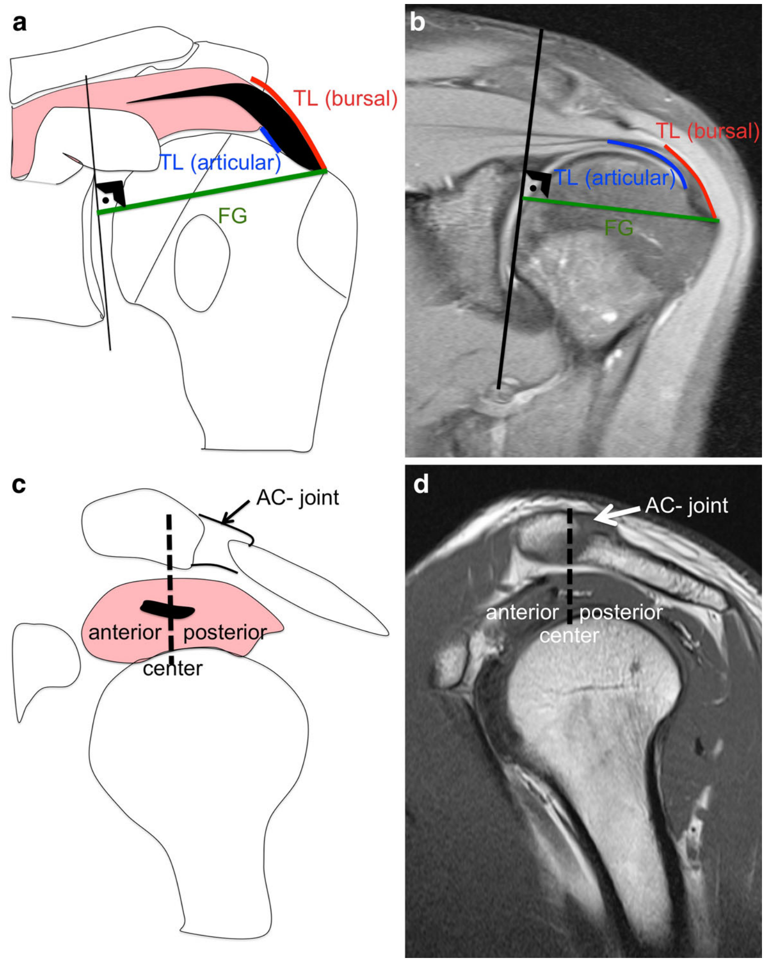

Fig. 1 **a** Schematic illustration of the oblique coronal view. Measurements: extramuscular tendon length at the bursal (TL bursal) and at the articular (TL articular) surfaces, each divided by the footprint-to-the-glenoid distance (FG), resulting in the bursal and articular TL/FG ratios. **b** Oblique coronal PDw FS TSE image as a real example with the same measurements. **c** Schematic illustration of the sagittal view. The sagittal view was used to define the appropriate oblique coronal sections for the anterior, central and posterior parts of the supraspinatus tendon, and the division into these three parts was always defined at the level of the AC joint. **d** Sagittal T1w SE image as a real example

Discussion

The most important finding of the present study was that the TL/FG ratios of the length of the supraspinatus tendon with partial tears were significantly different compared to the normal tendons, particularly at the bursal surface.

To understand the mechanisms of development and propagation of supraspinatus tears, measurement of tendon length may be helpful as it may be the only means to document failure in continuity. To achieve this goal, a ratio to characterize the relative length of the supraspinatus tendon is proposed. A ratio instead of an absolute value was chosen to take individual variations in the size of the shoulder joint into account.

The primary goal of surgery is to restore shoulder function, and therefore, restoring normal anatomy seems important. There is detailed knowledge about various aspects of the anatomy of the supraspinatus tendon, for example, the anatomy of the footprint [4, 23] and the thickness of the tendon at its insertion [23]. However, a measurement to assess the length of the supraspinatus tendon has not been available to date.

A lengthened tendon might cause biomechanical dysfunctions similar to those of a full-thickness tear. Therefore, in-continuity partial tearing might be as unfavourable as small full-thickness tearing, all with the potential of retraction of the musculotendinous junction and subsequent impairment of function and reparability.

Partial tears of the supraspinatus tendon can be classified according to the anatomical location of the tear (bursal, intratendinous and articular) and according to the depth (grade I: <3 mm, grade II: 3–6 mm and grade III: >50 % of the thickness of the tendon) [5, 27] or by a combination of the two characteristics [11]. There is, however, no classification regarding the tendon length so far.

There is no established consensus on treatment algorithms for partial tears of the supraspinatus tendon. Although some authors prefer surgical repair with the belief that a superior outcome can be achieved compared to conservative treatment [2], others recommend surgical repair for partial tears only if the tear involves more than 50 % of the tendon thickness. Most of the surgeons, however, combine clinical and radiological criteria to decide whether the patient would profit from a surgical

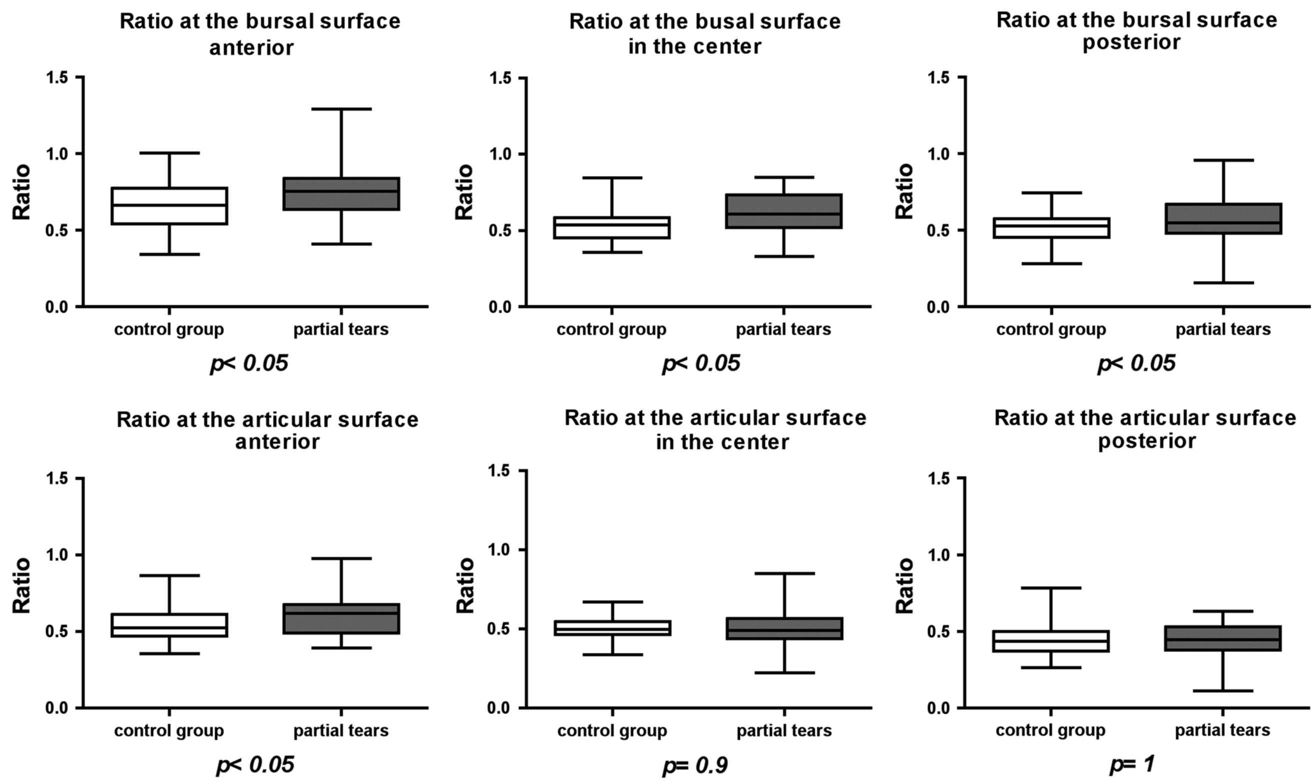

Fig. 2 TL/FG ratio (tendon length/footprint–glenoid distance) of the control group versus supraspinatus partial tears at the bursal and the articular surfaces of the tendon each in anterior, central and posterior parts. TL/FG ratios at the bursal surface of tendons with partial tears were significantly higher than those in the control group. At the articular surface, differences were significant only anteriorly. *Box plots* are depicted with whiskers from minimum to maximum, means and 95 % confidence interval

Table 1 Values for specificity, sensitivity, positive and negative predictive values as well as the area under the curve and the odds ratio with the confidence interval (CI) for defining a partial tear at the cut-off TL/FG ratio of 0.63 measured at the bursal surface in the central part of the supraspinatus tendon

Sensitivity (CI)	46 % (30–63 %)
Specificity (CI)	92 % (80–98 %)
Positive predictive value (CI)	81 % (58–94 %)
Negative predictive value (CI)	69 % (56–80 %)
Area under the curve (CI)	0.71 (0.6–0.83)
Odds ratio (CI)	9.56 (2.8–32.1)

intervention or whether rather a conservative approach should be employed first. The arguments in favour of or against surgical treatment, however, are mostly unscientific. We were not able to find a difference in length between partial tears with less compared to more than 50 % of the tendon thickness. Such a potential difference might have been lost due to a small sample size or by a multietiological mechanism including remaining tendon quality or anatomical tear pattern.

The results of this study should be interpreted with caution to the limitations; the effect of intra-articular application of contrast media, as performed in the case group and not performed in the control group, might have confounded the tendon length. However, the elasticity of the tendon is very small, and it is known that for a tendon lengthening of a few percentages, several hundred newton force would be needed [14]. Since such a force cannot be produced by an injection of contrast media, it is highly unlikely that the injection might have had a relevant effect on the tendon length. Therefore, we believe that the probability of such a potential confounding does not justify the ethical burden associated with risks of injection of the contrast media in healthy volunteers. Further, the mean age of the subjects with healthy tendons was lower (35 ± 9 years) than those with the partial tears (47 ± 8 years), and this might have theoretically introduced a potential confounder into the analysis. However, we found no correlation between tendon length and age in the control group, and the age range of the two groups was almost the same (22–59 years for the control group vs. 26–60 years for the case group). Therefore, age as a confounder to tendon lengths is considered unlikely. In addition, whether the here described retraction of the musculotendinous unit in partial tears was due to a change in the tendon geometry or a potential change in elasticity of

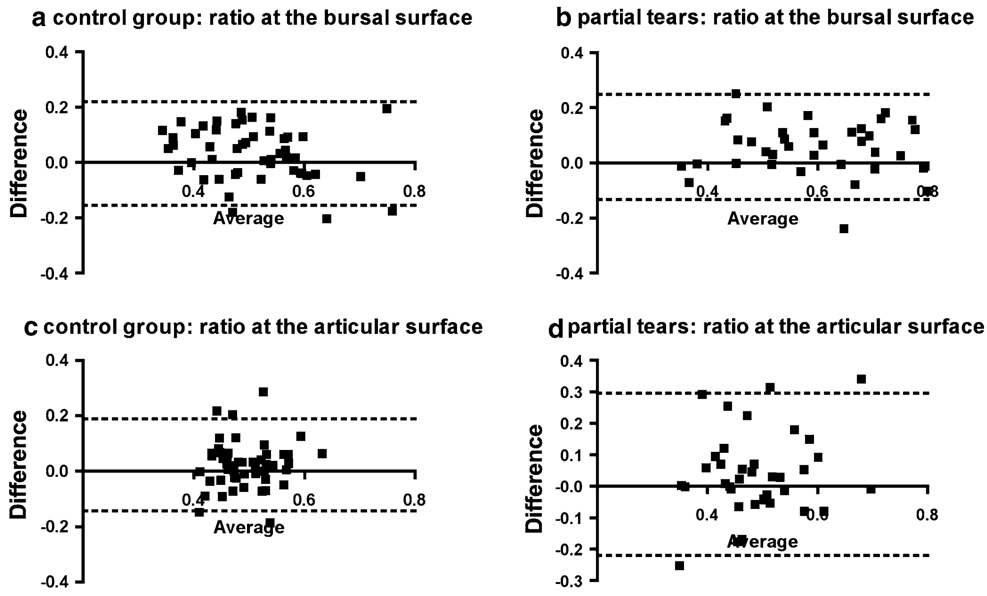

Fig. 3 *Bland–Altman plot*: Evaluation of the interobserver agreement. Agreement was better at the bursal surface of the supraspinatus tendon than at the articular surface

the tendon that might be present in degenerated tendinous tissue was not subject of the here performed investigation and cannot be answered.

Conclusion

It is possible to reproducibly measure the extramuscular supraspinatus tendon length. Partially torn supraspinatus tendons are longer, suggesting that there is failure in continuity, most reliably measurable at the bursal surface. A TL/FG ratio of >0.63 is highly suggestive of abnormal tendon lengthening. Since a lengthened tendon might cause biomechanical dysfunctions similar to those of a full-thickness tear, it seems more reasonable that the degree of tendon lengthening and thereby muscular retraction should become a rational argument for assessing the severity of the tear and thereby selecting treatment options in future.

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